APPARATUS AND METHODS FOR FILAMENT CRIMPING AND MANUFACTURING

PRIORITY AND RELATED APPLICATIONS

[0001] This application is a divisional of and claims priority to co-owned and co-pending U.S. patent application Ser. No. 12/691,562 of the same title filed Jan. 21, 2010, which is a divisional of co-owned U.S. patent application Ser. No. 11/473,567 of the same title filed Jun. 22, 2006 (now issued as U.S. Pat. No. 7,650,914), each of the foregoing incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0003] The present invention relates generally to the field of crimping, and in one salient aspect to fine filament crimping of, e.g., shaped memory alloy (SMA) wire.

DESCRIPTION OF RELATED TECHNOLOGY

[0004] The crimping of filaments such as metallic wires is well understood. Numerous techniques and configurations for wire and filament crimps are known. See for example, U.S. Pat. No. 5,486,653 to Dohi issued Jan. 23, 1996 entitled "Crimp-style terminal"; U.S. Pat. No. 6,004,171 to Ito, et al. issued Dec. 21, 1999 and entitled "Crimp-type terminal"; U.S. Pat. No. 6,056,605 to Nguyen, et al. issued May 2, 2000 entitled "Contact element with crimp section"; U.S. Pat. No. 6,232,555 to Besler, et al. issued May 15, 2001 entitled "Crimp connection"; U.S. Pat. No. 6,749,457 to Sakaguchi, et al. issued Jun. 15, 2004 entitled "Crimp terminal"; U.S. Pat. No. 6,799,990 to Wendling, et al. issued Oct. 5, 2004 entitled "Crimp connector"; and U.S. Pat. No. 6,893,274 to Chen, et al issued May 17, 2005 and entitled "Structure of ground pin for AC inlet and process for fastening wire onto same".

[0005] Similarly, the use of filaments, including those of shaped memory alloy (SMA), for various purposes is also well known. SMA generally comprises a metal that is capable of "remembering" or substantially reassuming a previous geometry. For example, after it is deformed, it can either substantially regain its original geometry by itself during e.g., heating (i.e., the "one-way effect") or, at higher ambient temperatures, simply during unloading (so-called "pseudo-elasticity"). Some examples of shape memory alloys include nickel-titanium ("NiTi" or "Nitinol") alloys and copper-zinc-aluminum alloys.

[0006] SMAs often find particular utility in mechanical actuation systems, in that it can be used to replace more costly, heavy, and space-consuming solenoid, motor driven, or relay devices. See for example, U.S. Pat. No. 4,551,974 to Yaeger, et al. issued on Nov. 12, 1985 and entitled "Shape memory effect actuator and methods of assembling and operating therefore"; U.S. Pat. No. 4,806,815 to Honma issued on Feb. 21, 1989 and entitled "Linear motion actuator utilizing extended shape memory alloy member"; U.S. Pat. No. 5,312,152 to Woebkenberg, Jr., et al. issued on May 17, 1994 and entitled "Shape memory metal actuated separation device"; U.S. Pat. No. 5,440,193 to Barrett issued on Aug. 8, 1995 and entitled "Method and apparatus for structural, actuation and sensing in a desired direction"; U.S. Pat. No. 5,563,466 to Renner, et al. issued on Oct. 8, 1996 and entitled "Micro-actuator"; U.S. Pat. No. 5,685,148 to Robert issued Nov. 11, 1997 and entitled "Drive apparatus"; U.S. Pat. No. 5,763,979 to Mukherjee, et al. issued on Jun. 9, 1998 and entitled "Actuation system for the control of multiple shape memory alloy elements"; U.S. Pat. No. 5,870,007 to Carr, et al. issued on Feb. 9, 1999 to "Multi-dimensional physical actuation of microstructures"; U.S. Pat. No. 6,236,300 to Minners issued on May 22, 2001 and entitled "Bistable micro-switch and method of manufacturing the same"; U.S. Pat. No. 6,326,707 to Gummin, et al. issued on Dec. 4, 2001 and entitled "Shape memory alloy actuator"; U.S. Pat. No. 6,379,393 to Mavroidis, et al. issued on Apr. 30, 2002 and entitled "Prosthetic, orthotic, and other rehabilitative robotic assistive devices actuated by smart materials"; U.S. Pat. No. 6,425,829 to Julien issued on Jul. 30, 2002 and entitled "Threaded load transferring attachment"; U.S. Pat. No. 6,574,958 to MacGregor issued on Jun. 10, 2003 and entitled "Shape memory alloy actuators and control methods"; U.S. Pat. No. 6,832,477 to Gummin, et al. issued on Dec. 21, 2004 and entitled "Shape memory alloy actuator"; U.S. Patent Publication No. 20020185932 to Gummin, et al. published on Dec. 12, 2002 and entitled "Shape memory alloy actuator"; U.S. Patent Publication No. 20040256920 to Gummin, et al. published on Dec. 23, 2004 entitled "Shape memory alloy actuators"; U.S. Patent Publication No. 20050229670 to Perreault, published on Oct. 20, 2005 and entitled "Stent crimper"; U.S. Patent Publication No. 20050273020 to Whittaker, et al. published on Dec. 8, 2005 and entitled "Vascular guidewire system"; and U.S. Patent Publication No. 20050273059 to Mernoe, et al. published Dec. 8, 2005 and entitled "Disposable, wearable insulin dispensing device".

DEFICIENCIES OF THE PRIOR ART

[0007] Despite the broad range of crimp technologies and implementations of SMA filaments, there has heretofore been significant difficulty in effectively crimping SMA filament wire when finer wire gauge sizes are chosen. Specifically, prior art approaches to crimping such filaments (including use of serrations or "teeth" in the crimp surfaces) either significantly distort or damage the filament, thereby altering its mechanical characteristics in a deleterious fashion (e.g., reducing its tensile strength or recovery properties), or allowing it to slip or move within the crimp. These problems are often exacerbated by changes in the environment (e.g., temperature, stress, etc.) of the SMA filament and crimp. Other techniques such as brazing, soldering, and the like are also not suitable for such fine-gauge applications.

[0008] Furthermore, no suitable solution exists for maintaining a constant and uniform tensile stress on the filament during crimping. Typical SMAs such as Nitinol can recover stress induced strain by up to about eight (8) percent. Therefore, in applications where filament length is relatively small, it is critical to maintain accurate spacing of the end crimping elements connected by the SMA wire after completion of the crimping process.

[0009] There is, therefore, a salient unsatisfied need for an improved crimp apparatus and methods of manufacture that specifically accommodate finer gauge SMA filament wire